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(54) IMPROVEMENTS IN OR RELATING TO MECHANO-ELECTRICAL TRANSDUCTION SYSTEMS

(71) We, SHIH-YING LEE of Huckleberry Hill, South Lincoln, Massachusetts, United States of America a citizen of the United States of America and YAO TZU LI of Huckleberry Hill, South Lincoln, Massachusetts, United States of America, a citizen of the United States of America. do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to mechano-electrical transduction systems.

Existing mechano-electric transducers normally operate on the principle of deriving output signal in accordance with the variation in the values of a set of sensing passive electric elements such as resistance, capacitance and inductance. In a conventional configuration, a set of four of these sensing elements is arranged in the form of a bridge excited by a regulated a.c. source with fixed amplitude, frequency and wave form. Because the output signal thus produced depends upon the impedances of the impedance elements, which are a function of the frequency, the system accuracy is, except in a purely null balance system, closely related to factors influencing the the stability of the excitation source, that is the amplitude, the frequency, the wave form and the source impedance.

Furthermore, since the output signal is, in general, a modulated signal produced by modulation of the excitation source by the transducer input signal, a demodulation involving phase sensitive rectification and filtering is needed to recover the input signal, except for a variable resistance bridge. While systems permitting the elimination of a separate phase sensitive rectifying have been devised, the need for a precision a.c. excitation source remains. U.S. Patent No. 3,012,192 describes one such circuit involving the hybriding on one-half a capacitive bridge with one-half of a phase sensitive diode bridge. In essence this hybrid system allows the elimination of a separate phase sensitive rectifying system, but the need for a precision a.c. excitation source remains.

Accordingly the present invention consists in a transducer system utilizing variations in the values of passive electric elements in response to an input quantity to be sensed to produce an electric output signal, said system comprising a source of D.C. excitation, a sensing circuit, said sensing circuit comprising two sensing networks each having an input terminal and an output terminal and containing passive electric elements, at least one of which elements is responsive to an input quantity to be sensed, and switching means between said D.C. source and the sensing circuit, said switching means having first and second excitation terminals connectable to high and low voltage levels of said D.C. excitation source, and having two output terminals respectively connected to an input terminal of the sensing networks, and having two input control terminals for controlling the times at which the two output terminals of the switching means are alternately switched to voltages substantially equal to said high and low voltage levels, said two input control terminals being connected to the respective output terminals of the sensing networks so that voltages developed at said output terminals of the sensing networks are fed back as control voltages to said input control terminals of the switching means, and the times at which said two output terminals of the switching means are alternately switched over are dependent on the response of said passive element of elements to the input quantity, whereby an electric signal can be taken from system output terminals which is a function of the input quantity to be sensed.

In the present invention, instead of rely-

ing on the frequency response of a sensing impedance element, which governs the preformance of most bridge-type circuits, the transient response to step function excitation is used. Through the use of switching techniques, response times of a network of which the sensing impedance elements are a part are used to trigger the application of the step function on and off to yield a pulse width modulated output which requires no rectification and which may, in some cases be recovered with simple filters. Thus, the regulated a.c. excitation is replaced by regulated d.c. excitation, which is more readily available in many industrial and military applications and which has only one parameter to consider.

In a particular embodiment of the present invention, a pair of sensing impedance elements is used to form a pair of identical electrical networks. A d.c. excitation source is provided, and each one of the sensing electrical networks is arranged to trigger alternately the application of the excitation to the other network whenever the output response of the first network reaches a predetermined value. The circuits are also arranged to bring the output of the first network to its initial condition while the second is excited and vice versa. As a result of the criss-cross triggering, the inputs to the pair of sensing networks appears as two square wave pulses, with the pulse width and the spacing between the pulses proportional, respectively, to the response time of the two networks. One convenient way of providing an output is to utilize the difference of the average of the two pulse trains as the output signal, a step which requires some filtering but no rectification.

While in principle the sensor network may assume any convenient network form, for transducer application the most readily applicable circuits are of the form with first order dynamic lag such as the R-C, L-R circuit with a first order time constant as the dominating characteristic. Thus response time of this first order delay is proportional to the variation of either of the sensing electric parameters R, C or L in the circuit. These first order circuits yield linear output-input relationships as will be more fully described hereinafter. However, in some special applications a higher order or nonlinear circuit may be desirable to give specific nonlinear behavior or to introduce compensation effects in a non-ideal situation.

The invention will be described further, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a schematic circuit diagram of a first embodiment according to the present invention;

Figure 2 illustrates wave-form diagrams relating to the operation of the circuit of Figure 1;

Figure 3 illustrates a first pair of capacitors actuated by linear mechanical motion and suitable for use in the circuit of Figure 1;

Figure 4 illustrates a second pair of capacitors arranged so that linear mechanical motion produces a variation in capacity;

Figure 5 is a schematic diagram of a second embodiment of the invention utilizing a multivibrator as a switch means;

Figure 6 is a schematic diagram of a modification of the embodiment of Figure 5;

Figure 7 illustrates wave forms relating to the operation of the circuit of Figure 6;

Figure 8 is a detailed schematic circuit diagram of a third embodiment of the invention;

Figure 9 is a representation by switches and impedance of a multivibrator circuit of Figure 8;

Figure 10 is a schematic diagram of a modification of the circuit of Figure 5 to ensure oscillation;

Figure 11 illustrates a voltage transfer function relating to the operation of Figure 10;

The operating principle of the invention may be illustrated by the schematic diagram of Figure 1. A voltage source has a high voltage terminal E_h and a low voltage terminal E_L and can be coupled alternately to a pair of sensing networks 1 and 2 through a set of double throw switches 3 and 4. As depicted in the diagram of Figure 1, the switches are shown in the upper position with switch No. 3 connecting the high voltage terminal E_h to the sensing network 1, switch 4 connecting the low voltage terminal E_L to an input of sensing network 2, and switch 5 connecting the output of the sensing network 2 to the earth. It is known to employ as many switches as there are energy storages in the circuit to ensure identical initial conditions, even though in certain designs switches may be replaced by diodes. (In Figure 1 diodes 11 and 13 could be used to replace switch 5).

In the portion of the operating cycle illustrated in Figure 1, the sensor network 1 is excited by the high voltage source. Network 1 has started from an intial condition of the specified low voltage which was ensured by the preceding cycle and in which the output side of sensing circuit 2 was clamped to earth corresponding to the clamping state now prevailing at the output side of network 2. For a first order R-C impedance as illustrated, the response of the output of the circuit is an exponential function of time, given by:

$$e_{o1}=(E_h-E_L)\,\varepsilon EXP(-t_1/RC_1)=\Delta e\,\varepsilon EXP(-t_1/RC_1) \qquad (1)$$

where

e_{o1}=output voltage of first sensor circuit
E_h=high voltage level
E_L=low voltage level
εEXP=natural base exponential
t=time
R=resistance of impedance circuit network
C=capacitance of impedance of circuit network and subscript 1 or 2 specifies the channel.

The output voltage e_{o1} of network 1 is compared with a predetermined reference voltage E_r and a trigger-and-hold circuit 9 is used to follow this output voltage comparator to energize lower switch actuator 6 which in turn reverses the switches 3, 4 and 5 and thereby initiates the next cycle.

The time sequence of the switches and the voltages of the circuit of Figure 1 for two complete cycles are shown in Figure 2.

The output of the system as shown in Figure 1 is taken across the input terminals 7 and 8 of the two impedance networks. Effectively this means that the system output e_{out} is equal to the difference of e_{i1} and e_{i2}, the voltages at the input terminals 7 and 8 of sensing networks 1 and 2. Thus

$$e_{out}=e_{i1}-e_{i2} \qquad (2)$$

as shown in the bottom of Figure 2. Ideally the average of e_{out} is

$$\bar{e}_{out}=\Delta e\frac{T_1-T_2}{T_1+T_2} \qquad (3)$$

where

T_1=time for first circuit to reach reference voltage
T_2=time for second circuit to reach reference voltage and
Δe=the difference between E_h and E_L.

In practice, when conventional filters are used, this average d.c. output has superimposed upon it the ripples resulting from the filtering of the harmonic content of the square wave. For practical purposes, however, this ideal d.c. output $\bar{e}_{out}$ is of primary interest to the transducer user.

In the circuit of Figure 1, T_1 and T_2 are determined by the response time of the two networks to reach the reference voltage. Thus for first order systems, we have by solving for t in equation 1 when $e_{o1}=e_r$:

$$T_1=R_1 C_1 \log\frac{E_h-E_L}{e_r} \qquad (4)$$

$$=C_1 K$$

Similarly,

$$T_2=C_2 K$$

where

$$K=R \log\frac{E_h-E_L}{e_r}=\text{constant} \qquad (5)$$

$(R_1=R_2$ in Figure 1)

Substituting (5) into (3) we have

$$\bar{e}_{out}=\Delta e\frac{C_1-C_2}{C_1+C_2} \qquad (6)$$

C_1 and C_2 may be usually arranged in a push-pull manner so that while C_1 is increasing when the transducer is being subjected to an input signal, C_2 is decreasing correspondingly. Moreover, in responding to the transducer input signal, C_1 and C_2 may vary either in direct proportion or to the reciprocal of the transducer input. A typical example for the former case may be found when a sliding-gate type capacitance is involved. In this case the input of the transducer is mechanical and would effect a displacement of the push-pull pair by increasing the overlapping area of one while decreasing that of the other as shown in Figure 3. Assuming the capacitance is in direct proportion to the overlapping area, and therefore, the displacement, then

$$C_1=C_0+x\ k_2 \qquad (7)$$
$$C_2=C_0-x\ k_2$$

where

C_0=mean capacitance
x=mechanical displacement
k_2=sensitivity constant

Substituting (7) into (6), then

$$\bar{e}_{out}=\Delta e\frac{x\ k_2}{C_0} \qquad (8)$$

which shows that $\bar{e}_{out}$ is a linear function of the mechanical displacement input x. This would make the overall system sensitivity linear, and the same applies if the transducer input to be measured is some other physical parameter which varies in direct proportion to the mechanical input x. In other words, a linear performance can be achieved when the impedance variation is in direct proportion to the transducer input.

In the second type of impedance variation the impedance is a reciprocal function of the transducer input. A typical example may be found in the case of gap variation type capacitance as shown in Figure 4. In this type of mechanical configuration.

$$C_1 = \frac{C_0}{1-r} \qquad (9)$$

$$C_2 = \frac{C_0}{1+r}$$

where C_0 is the capacitance of each side when the plate is centered and the term r is defined such that

$$r = \frac{x}{x_0} \text{ with } x_0 = \text{normal gap.}$$

Substituting (9) into (6) then

$$\bar{e}_{out} = \Delta e r$$

$$= \Delta \frac{x}{x_0} \qquad (10)$$

Again, a linear performance is achieved for the gap-type capacitance as illustrated in equation (10). This linear property would apply equally well for a gap varying type of variable inductance sensor when it is used in a similar configuration.

While variable reactances have been used in the above discussion of transducer operation, variable resistors can also be used. The analysis is then similar to that set forth above. For example, equation (4) becomes:

$$T_1 = R_1 K \qquad (4)'$$

and equation (5) becomes

$$T_2 = R_2 K \qquad (5)'$$

While the schematic diagram of Figure 1 illustrates the basic operating principle of the invention, various simplified configurations are available to give the desired performance. The first simplification involves the replacement of clamping switch 5 of Figure 1 with a pair of diodes 11 and 13 across $e_{i1} - e_{o1}$ and $e_{i2} - e_{o2}$, respectively, as shown in Figure 1. Although both the clamping switch 5 and diodes 11 and 13 are shown in Figure 1, only the clamping switch or the diodes would be used. The polarity of the diodes as shown would assume an "open circuit" condition when a sensor impedance circuit is excited by E_h and "short circuit" condition when connected to the lower voltage terminal E_L. If other circuit conditions called for clamping the "charge" rather than "discharge" portion of the circuits, the diode polarity would be reversed.

Figure 5 shows a schematic circuit utilizing a multivibrator unit, sometimes also known in the art as a flip-flop, as the switching means. The multivibrator 10 has two excitation terminals 12 and 14 which are connected to the high and low voltage excitation sources, respectively. The multivibrator has two output terminals Q and $\bar{Q}$ which are internally switchable to voltages substantially equal to the high and low excitation voltages. The output of the circuit is provided across terminals Q and $\bar{Q}$. These terminals also provide the input to the two sensing networks. The first network, connected to output Q, consists of resistor 16 and sensing capacitor 18. The second network, connected to output $\bar{Q}$, consists of resistor 20 and sensing capacitor 22. Diodes 24 and 26 are paralleled with resistors 16 and 20 to reduce discharge times. The common terminal of capacitors 18 and 22 is connected to the lower excitation voltage E_L. Zener diodes 28 and 30 in the feedback paths ensure a precise switching point.

The multivibrator is so constructed that the two output terminals Q and $\bar{Q}$ must have different voltage levels if only one input S or R is energised. The two input terminals S and R are often referred to as the set and reset input terminals. The relationship between the two input terminals and the two output terminals can be summarised by the table set forth below as Table I.

TABLE I

S	R	Q	$\bar{Q}$
1	0	1	0
0	0	1	0
0	1	0	1
0	0	0	1
1	1	1	1

Those skilled in the electronic arts involving multivibrators and flip-flops will recognize that the symbol 1 in the table signifies a high voltage condition, and the symbol 0 signifies a low voltage condition.

The multivibrator switching means has another property which is useful for the invention, that is its toggle action. When a signal at S or R reaches a certain predetermined value, the output Q and $\bar{Q}$ will change state in conformance with the table very

quickly. There is no change whatever before this signal level is reached. The wave forms involved in the operation of the circuit of Figure 5 are substantially the same as those shown in Figure 2 for embodiment of Figure 1.

It may be noted that in the circuit of Figure 5 the two sensing capacitances have a common lead. Another arrangement of the sensing networks is shown in Figure 6. With this arrangement, the sensing networks are connected in a criss-cross fashion between the two output terminals and there is no common lead for the two capacitances. The wave forms are quite different in this case and are shown in Figure 7. It will be noted that there is an initial overshoot in the voltage at the capacitor so that in effect the voltage at the capacitor is doubled. Therefore, while it may be inconvenient not to have the common lead, the circuit is particularly desirable for conditions in which low value capacitors must be used.

Figure 8 illustrates a complete circuit diagram of a typical multivibrator unit together with the sensing circuits and triggering means. The basic multivibrator circuit is shown in the dotted line block 32 of Figure 8. Multivibrator circuits are well known in the electronic arts, and a detailed description of the operation of this circuit is omitted here. It should be noted, however, that this symmetrical circuit consists of a pair of regenerative amplifier segments 34 and 36 so that as soon as the control voltages 38 and 40 of respective segments reaches a certain level, the output 42 or 44 of the respective segment will plunge instantly to a low level. Internal coupling networks 46 and 48 are used to perform cross-triggering so that when output 42 plunges down, its effect is to propagate to section 36 through network 46 and thereby bring output 44 up.

A bistable circuit has the inherent property of remaining stable while having either side at a high or low voltage level until the control voltages, in this circuit at 38 or 40, are subjected to a change. In the present arrangement this change is effected by charging the sensor capacitances 50 and 52 through the resistances 54 and 56 respectively. A pair of zener diodes 58 and 60, may also be used between inputs 38 and 40 of the multivibrator circuit and the sensor capacitances, 50 and 52, to provide the proper voltage bias and sharp triggering action resulting from the non-linear resistance property of the zener diode. The diodes 62 and 64 are used to provide the clamping of the circuit to the low voltage level as discussed before in conjunction with Figure 1. The outputs of this system are taken across terminals 42 and 44.

The operation of this circuit may be described progressively starting with the assumption that output 42 is at the beginning of a high voltage level and output 44 is at a low voltage level. Sensor capacitance 50 will be charged through resistance 54 and thus raise the voltage at point 38. As soon as the voltage at the control terminal 38 reaches the triggering level of the circuit, the output voltage 42 of section 34 immediately plunges downward to a low voltage level. This sudden drop in voltage propagates through the capacitance of circuit 46, produces a higher voltage at control point 40 and thereby brings the voltage at output terminal 44 of section 36 to the high voltage level, and thereby starts the charging cycle of sensing condenser 52. This sudden rise of voltage at terminal 44 propagating through circuit 48 increases the recently raised voltage at terminal 38 to help hold the voltage at terminal 42 at the low level. The charging up of capacitance 52 then repeats a sequence similar to that just described.

In the circuit of Figure 8 the high and low voltage levels experienced by the multivibrator output terminals 42 and 44 are generated by the circuit parameters and are not the same as the positive voltage at 72 and the ground voltage at 74. However, in practice the high voltage levels at 42 and 44 are practically equal to the positive voltage at 72. This is because in the conducting state the resistances across the supply terminal 72 and the output terminals 42 and 44 through the common resistance 76 and the corresponding transistors 78 and 70 are quite low in comparison to other load resistances.

The multivibrator circuit of Figure 8 can also be characterised by the switches shown in Figure 9 with the associated resistances 85 through 92. Switch 78′ of Figure 9 together with resistances 85 and 87 represents the two operation states of the transistor 78 of Figure 8. Likewise, this is true for switches 80′, 79′, and 81′ with respect to the correspondingly numbered transistors.

In the diagram of Figure 9, the length of the resistance symbol represents the size of the resistance: a short one represents a low resistance while a long one means a large value. Thus when all the switches are in the upper position as shown, the voltage at 42 would be nearly equal to the supply voltage at 72′ while the voltage at 44 would be nearly equal to the ground voltage at 74′. The reverse situation would be true if the switches were in a down position. If all the high resistances approach open circuit, then the four double throw switches of Figure 9 can be combined to two double throw switches as illustrated in Figure 1.

The resistances 85 through 92 of Figure 9 represent the characteristics of the transistor pairs. There symmetry and stability are essential for precision transducer action.

A modification of the arrangement of Figure 5 is shown in Figure 10. In this embodiment, a pair of field-effect transistors 124 and 126 have been added. The principal other change in the circuit from that of Figure 5 is the reversal of the polarity direction of diodes in parallel with the charging resistors in the two sensing networks and the reversal of the input leads to which the feedback loops from the outputs are connected. The field-effect transistors 124 and 126 together with their series resistors 128 and 130 serve as voltage inverters. That is when the input voltage to the gate of the transistor goes up, the output voltage of the transistor goes down. This voltage relationship is shown in Figure 11. The operating point is chosen so that a very small variation in the gate voltage V_g can cause a very large variation in output voltage Vs. Thus a very sharply defined switching voltage and operation is obtained. As noted above, with the inversion in the feedback path produced by the field-effect transistors 132 and 134 the polarity of the diodes 136 and 138 and the connection of the feedback leads to the input terminals S and R are both reversed.

An important advantage of the circuit of Figure 10 over that of Figure 5 is that it has no "stall" condition. If one examines Figure 5 and the table of the multivibrator Table I, one can see that while most starting conditions result in an oscillatory condition with the wave forms similar to those shown in Figure 2, it is possible for the initial condition to be that shown by the last line of the table. That is both inputs and both outputs might by chance be in the ONE state when the circuit is energised. This condition is a "stall" condition since the ONE outputs results in ONE inputs which would produce ONE outputs. This stable condition could be disturbed, of course, by some external or internal disturbance which could purposefully be introduced. With the modification of Figure 10, a "stall" condition can never exist. If both outputs are in the ONE state, the inversion in the feedback path produced by the field-effect transistors will produce ZERO inputs. If both inputs are ZERO, the outputs will be in the ZERO, ONE state, and the circuit will be started in an oscillatory state. With the inversion, there is no "stall" state.

While the feedback inversion of Figure 10 has been shown as applied to the circuit of Figure 5, it could equally well be applied to the circuit of Figure 6. While the wave forms would be different, the prevention of a stall condition would be achieved.

The schematic of Figure 1 and the embodiment of Figure 8 are illustrative of the present invention. Variations of these basic configurations may be realised either with additional sophistication to ensure better regulation of the various voltage levels pertinent to the accuracy of the system, or, on the other hand, by omitting some features in exchange for simplicity.

For convenience, the above embodiments have been shown with R-C circuits, with capacitance as the primary sensing impedance element. Typical applications are a variable capacitance pressure cell or accelerometer or a temperature sensitive capacitance. If an arrangement such as the circuit of Figure 8 is used with a 6 volt d.c. source and a pair of variable capacitors in the 50 $\mu\mu$f range, an output of the order of several volts can be produced with a linear range substantially wider than that attainable with prior art arrangements.

Since an a.c. input is not utilised in the embodiments of this invention, no frequency or wave-form control is necessary. Moreover, the excitation voltage can be converted with small loss input output voltage signals. Since the output terminals are clamped by the switches to the excitation source, output load has very little effect on the output signal.

Referring again to Figure 8, resistor 54 or 56 may be provided in adjustable rather than a fixed form. In that case, the null balance for zero signal can be achieved by varying the value of one of the resistors to balance out minor variations in the values of circuit components. A temperature induced problem of transducer equipments is that of changes in null balance produced by changes in temperature. By providing corresponding elements in the two passive networks, for example, resistors 54 and 56, with different thermal coefficients, the change in relative characteristics produced by this difference in thermal coefficient can be made to exactly compensate for changes in null balance otherwise produced by the thermally induced changes in circuit output. With typical components satisfactory compensation may be provided by selection from a relatively small group of transistors, selecting a combination to provide a null balance at two widely spaced points in the thermal range.

Furthermore, by using a group of resistors for one of the elements, for example, resistors 53, 54 and 55 rather than merely resistor 54, the resistors 53, 54 and 55 having predetermined different thermal coefficients, thermally induced changes in circuit sensitivity may be compensated. Considering equations (3), (5) and (6), for example, it will be seen that the change in sensitivity with temperature is a function of the change in the value of the charging resistance with temperature. With selection of a group of three resistors to match sensitivity at separated points in the thermal range, excellent thermal sensitivity correction can be achieved. An extensive discussion of the factors involved in correcting for sensitivity changes is set forth in U.S. Patent No.

3,248,936 entitled "Temperature Compensated Transducer".

In some cases circuit or component characteristics may produce a non-linear output. In such situations linearity may be improved by providing capacitors in parallel with the charging resistors if an RC network is used. In Figure 5, for example, capacitors 140 and 142 would be added in parallel with resistors 16 and 20. These capacitors are otherwise unnecessary and would not be used unless additional linearity correction is needed.

Although our invention has been described with respect to certain specific embodiments, it will be apparent to those skilled in the transducer and electronic arts that other combinations and modifications of the features and elements disclosed may be made without departing from the scope of our invention, which is defined on the appended claims.

WHAT WE CLAIM IS:—

1. A transducer system utilizing variations in the values of passive electric elements in response to an input quantity to be sensed to produce an electric output signal, said system comprising a source of D.C. excitation, a sensing circuit, said sensing circuit comprising two sensing networks each having an input terminal and an output terminal and containing passive electric elements, at least one of which elements is responsive to an input quantity to be sensed, and switching means between said D.C. source and the sensing circuit, said switching means having first and second excitation terminals connectable to high and low voltage levels of said D.C. excitation source, and having two output terminals respectively connected to an input terminal of the sensing networks, and having two input control terminals for controlling the times at which the two output terminals of the switching means are alternately switched to voltages substantially equal to said high and low voltage levels, said two input control terminals being connected to the respective output terminals of the sensing networks so that voltages developed at said output terminals of the sensing networks are fed back as control voltages to said input control terminals of the switching means, and the times at which said two output terminals of the switching means are alternately switched over are dependent on the response of said passive element or elements to the input quantity, whereby an electric signal can be taken from system output terminals which is a function of the input quantity to be sensed.

2. A transducer system according to claim 1, wherein the system output signal is the difference between two pulse trains whose pulse durations are controlled by the respective sensing networks.

3. A transducer system according to claim 1 or 2, wherein the switching means comprises a multivibrator having first and second output terminals connected to the respective input terminals of the sensing networks.

4. A transducer system according to claim 3, wherein the multivibrator has set and reset terminals being the input control terminals which are connected respectively to respective output terminals of the sensing networks.

5. A transducer system according to claim 1, 2, 3 or 4, wherein the system output is taken off between the input terminals of the sensing networks.

6. A transducer system as claimed in claim 4 or 5, wherein the sensing networks comprise a pair of resistance-capacitance circuits, at least one impedance in the resistance-capacitance circuits serving as a mechano-electrical transducer, a predetermined voltage level within each of the resistance-capacitance circuits serving to actuate the associated control terminal, whereby the electric signal at the system output terminals provides an output proportional to the input to said transducer.

7. A transducer system as claimed in claim 4 or 5, wherein each of the sensing networks comprises a resistance and a capacitance, first and second unidirectional circuit elements connected in parallel with each of the resistances, respectively, whereby the terminals associated with an energy storage element of each network are clamped to a reference voltage during the portions of the cycle that the other network is operative, a terminal associated with an energy storage element of each of the networks being connected to a control terminal of the multivibrator, a capacitance of at least one of the sensing networks serving as a sensing transducer, whereby the electric signal between the system output terminals is a function of the variation in the value of the sensing transducer.

8. A transducer system as claimed in claim 4 or 5 wherein each of the sensing networks includes a resistance and a capacitance, a unidirectional circuit element connected in parallel with each of the resistances, the resistance and capacitance of each of the networks being connected in series, an inverter connected to the junction of the resistance and capacitance of each of the networks, each of the inverters being connected to a control terminal of the multivibrator, a capacitance of at least one of the passive networks serving as a sensing transducer, whereby the electric signal between the system output terminals is a function of the variation in the value of the sensing transducer.

9. A transducer system as claimed in any one of claims 1 to 7 wherein said sensing circuit includes a series resistance capacitance combination, the capacitance of the capacitor varying in response to the input being sensed.

10. A transducer system as claimed in any one of Claims 1 to 5 wherein said sensing circuit includes a series resistance inductance combination, the inductance of the inductor varying in response to the input being sensed.

11. A transducer system as claimed in Claim 8 or 9 wherein a unidirectional circuit element is connected in parallel across the resistor to reduce, in one direction, the response time of said network.

12. A transducer system as claimed in any preceding claim wherein zener diodes are employed to determine the control voltages controlling the switching means.

13. A transducer system as claimed in any of Claims 1 to 11 wherein circuit elements having a very steep input-output characteristic are employed to determine the control voltages which control the switching means.

14. A transducer system as claimed in any preceding claim wherein one of the passive electric elements in one of the sensing networks is variable to provide a null balance for zero signal conditions by changing the charging characteristics of said one network.

15. A transducer system as claimed in any one of claims 1 to 13 wherein at least one circuit element in one of the sensing networks has a thermal resistance coefficient different from corresponding element or elements in the other sensing network whereby changes in system null balance which would otherwise be produced by changes in temperature are eliminated by the cancelling effect of thermally produced changes in circuit parameters.

16. A transducer system as claimed in any one of claims 1 to 13 wherein the sensing circuit comprises a group of elements with predetermined thermal resistance coefficients whereby changes in circuit sensitivity which would otherwise be produced by changes in temperature are eliminated by the cancelling effect of thermally produced changes in circuit parameters.

17. A transducer system constructed, arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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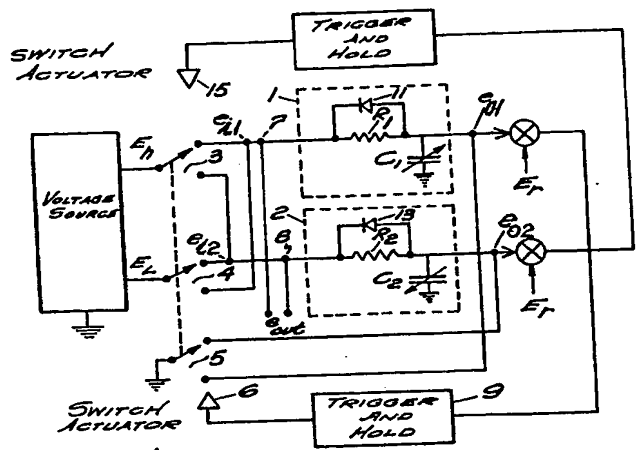

Fig. 1

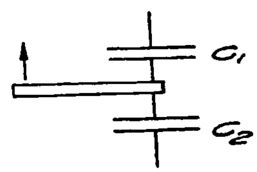

Fig. 4

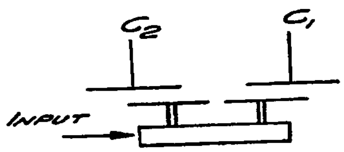

Fig. 3

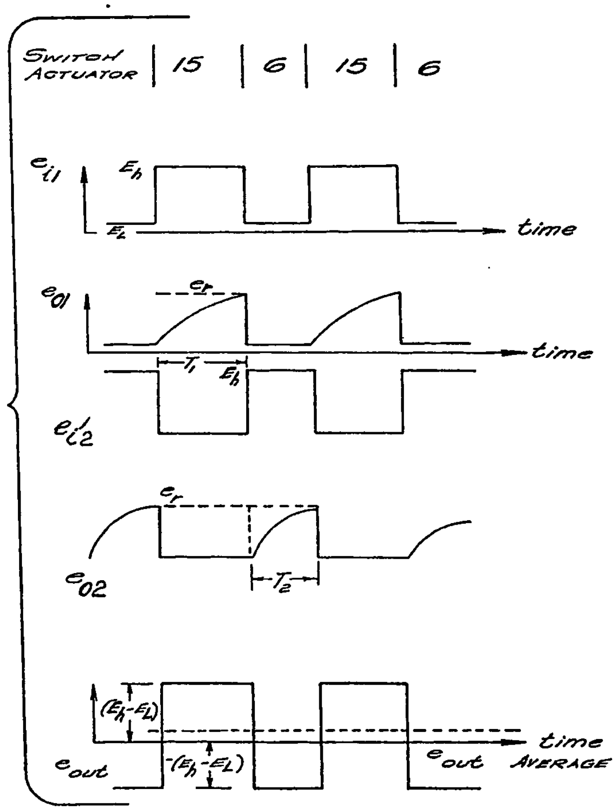
SWITCH ACTUATOR
15
6
15
6
e_{i1}
E_h
E_L
time
e_{01}
e_r
time
T_1
E_h
e'_{i2}
e_r
e_{02}
T_2
(E_h-E_L)
$-(E_h-E_L)$
time
e_{out}
e_{out} AVERAGE

FIG. 2

1255631 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

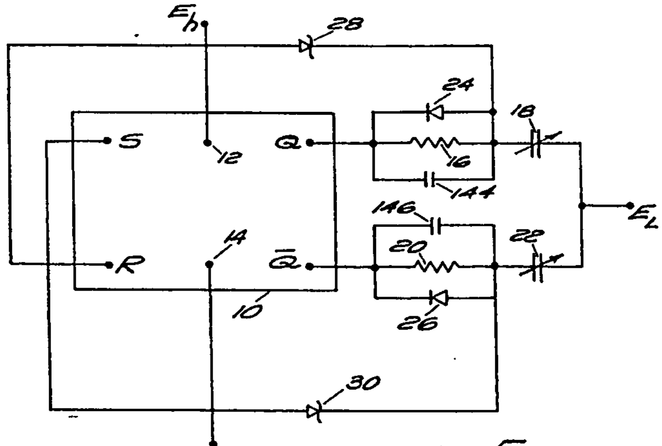

Fig. 5

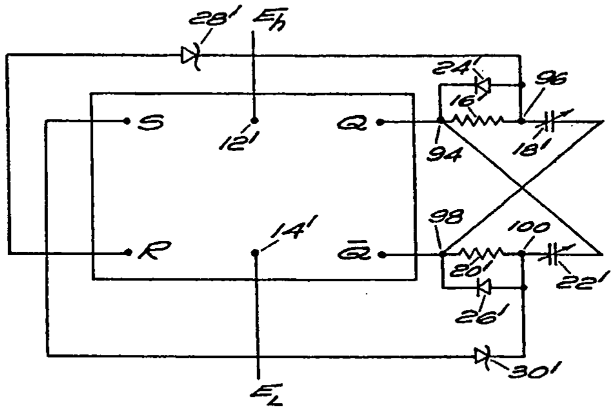

Fig. 6

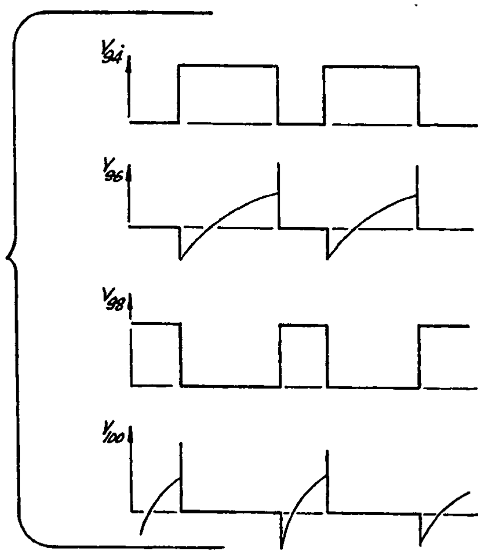

Fig. 7

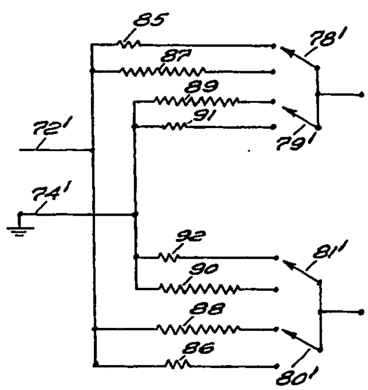

Fig. 8

1255631 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

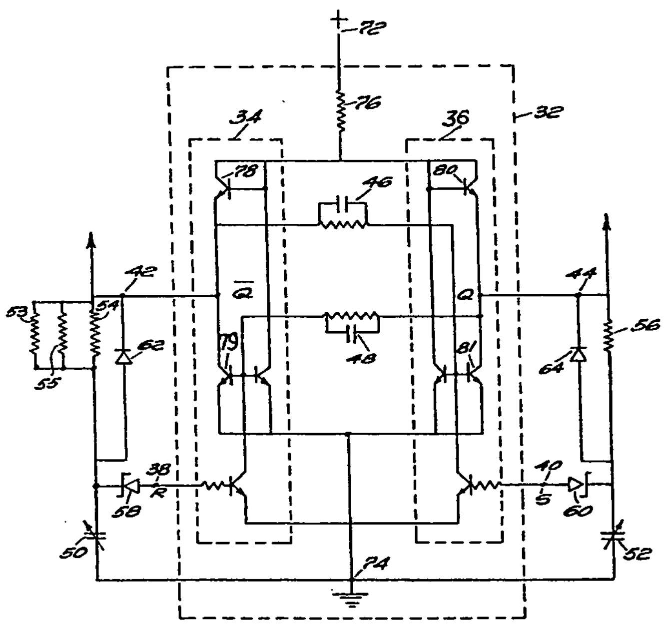

Fig. 8

1255631 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

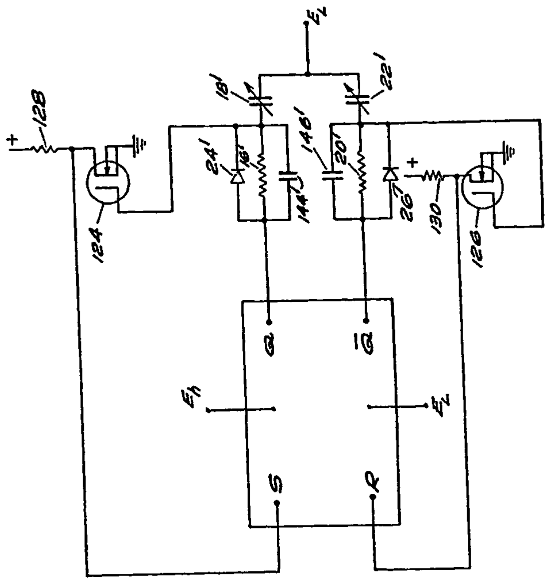

FIG. 10

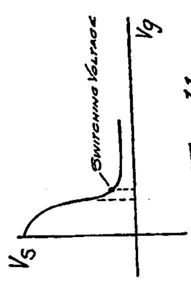

FIG. 11